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THE  
JOURNAL OF GEOLOGY

APRIL-MAY, 1913

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CHEMICAL COMPOSITION AS A CRITERION IN IDENTIFYING METAMORPHOSED SEDIMENTS<sup>1</sup>

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I

In 1909 the writer contributed to this *Journal*<sup>2</sup> an article under the title given above. In the present pages it is his desire to correct some apparent misunderstandings of the import of the data there presented and to offer some additional data since obtained.

The idea that chemical composition may in some cases furnish a clue to the origin of a metamorphic rock is nothing new. It was formulated in general terms by Rosenbusch and has been given recognition by Grubenmann, Van Hise, Adams, and others.

The postulate is a very simple one, namely: that certain well-known and characteristic changes in chemical composition produced in the processes of rock weathering and assortment may be recognizable even when the resulting product has been dynamically metamorphosed.

The writer in his previous article attempted to test with some care the value of each of the chemical criteria which earlier writers had suggested, and the method adopted was the comparison of

<sup>1</sup> Published with the permission of the Director of the U.S. Geological Survey.

<sup>2</sup> *Jour. Geol.*, XVII (1909), 445-72.

analyses of a large number of sedimentary slates and schists with a much larger number of analyses of igneous rocks. Such a statistical study, the assembling of analyses which were selected judiciously but impartially, offered, he believed, a viewpoint from which the *rule* could be perceived in the midst of the numerous *exceptions* which special conditions introduce. The result of this study was to confirm in general the beliefs of the geologists who had earlier considered this problem. In addition conclusions were reached as to the relative critical value of various chemical relationships.

J. D. Trueman in a recent number of this *Journal*<sup>1</sup> summarized in a very useful manner the various criteria that had been applied for determining the origin of schists. In the section devoted to chemical criteria he recognized that these may be of service in some instances, but he seemed in general inclined to attribute small importance to them.

As Mr. Trueman was good enough to refer to my article on this subject, I wish here to consider some of the objections which he raised and to elucidate further certain of the arguments that were brought forward in the original paper. Mr. Trueman's untimely death last summer while engaged in geologic field work must be a source of deep regret to those who are familiar with his work and I take this opportunity to express my appreciation of the high value of the contribution he has made to the literature on metamorphism. Agreeing with most of his conclusions, if I take exception to a few of them it is in the belief that no true scientist regards his results as final but is eminently satisfied if his work stimulates others and contributes somewhat to the progress toward a more complete knowledge of Nature's laws.

The principal criteria which have been appealed to in support of sedimentary origin of a fresh crystalline schist are: (1) dominance of magnesia over lime, (2) dominance of potash over soda, (3) the presence of alumina in large excess over the 1:1 ratio necessary to satisfy the alkalis present. It should be particularly emphasized that the *amount of the excess* of potash, magnesia, or alumina is of great importance, a magnesia-lime ratio of 4:1 being immensely

<sup>1</sup> *Jour. Geol.*, XX, No. 4, pp. 300-311.

more significant than a  $1\frac{1}{2}:1$  ratio, and 10 per cent excess alumina having several times the diagnostic value of a 5 per cent excess.

In attempting to compare in a general way the *relative* merits of various chemical criteria, the writer possibly conveyed a stronger impression of their individual worth and potency than he would at present desire to do. Few reputable physicians are content to diagnose a disease from a single symptom, but when several symptoms all point to a common cause a diagnosis may be made with security. To follow the parallel, the chemical relationships used as criteria are symptoms which considered singly might result from several causes, but taken collectively are known to result from only one<sup>1</sup> cause, rock weathering and assortment. In actual practice the geologist is seldom required to depend entirely upon chemical criteria but is aided in his diagnosis by structural and textural features as well.

The principal results of the writer's comparisons of analyses of meta-sedimentary with igneous rocks may be summed up in the following table in which the figures in parentheses show the number of analyses of each class of rocks entering into the comparison.

TABLE I

	Percentage Weight of MgO>CaO	Percentage Weight of K <sub>2</sub> O>Na <sub>2</sub> O	Percentage Weights of Both MgO> CaO and K <sub>2</sub> O>Na <sub>2</sub> O	Over 5 Per Cent Excess* Al <sub>2</sub> O <sub>3</sub>	Over 10 Per Cent Excess* Al <sub>2</sub> O <sub>3</sub>
Sedimentary slates.....	(79) 84 per cent	(74) 92 per cent	(74) 78 per cent	.....	.....
Pelite schists and gneisses.....	(30) 77 per cent	(30) 83 per cent	(30) 74 per cent	(30) 63 per cent	(30) 30 per cent
Igneous rocks of Washing- ton's <i>Tables</i> of <i>Analyses</i>	<div> <div>Classes I and II..</div> <div>All other classes...</div> </div> <div> (1481) 8 per cent (411) 35 per cent </div>	<div> (1481) 36½ per cent (401) 14 per cent </div>	<div> (1481) 4½ per cent (401) 7 per cent </div>	<div> (1892) Less than 3 per cent </div>	<div> (1892) About 0.6 per cent </div>

\* By "Excess Al<sub>2</sub>O<sub>3</sub>" is meant the alumina in excess over the  $1:1$  ratio in which it is combined with lime and the alkalis in the aluminous silicates. If the "norm" is calculated according to the method of the *Quantitative Classification of Igneous Rocks*, this excess appears as corundum.

The meaning of the table may be made clearer by interpreting its third column. This column shows that of 74 analyses of sedi-

<sup>1</sup> A partial exception in hydrothermal metamorphism will be referred to later.

mentary slates 78 per cent showed a dominance both of magnesia over lime and of potash over soda. In 70 analyses of pelitic schists and gneisses this relationship is almost equally characteristic, holding in 74 per cent of the analyses. In the more siliceous igneous rocks (Classes I and II), on the other hand, dominance of magnesia over lime and of potash over soda occurs in only  $4\frac{1}{2}$  per cent of the 1,481 analyses considered, and in the case of all the other igneous rocks (Classes III, IV, and V) in only 7 per cent of the 401 analyses considered. The contrast between igneous rocks and sediments shown in the other columns is also striking. Such wide differences as are here exhibited can hardly be fortuitous, and the nature of data upon which they are based would seem to recommend them to the serious consideration of geologists.

In criticism of the value of the potash-soda and magnesia-lime ratios as criteria of genesis, Mr. Trueman<sup>1</sup> states that "in the case of many, possibly in the majority of, igneous rocks *either* the MgO is in excess over the CaO or the K<sub>2</sub>O over the Na<sub>2</sub>O . . . ." and points out with perfect correctness that "the tables of Washington show that in the majority of igneous rocks *containing over 70 per cent of silica* the K<sub>2</sub>O is in excess over Na<sub>2</sub>O. . . . Accordingly while the double relationship is apparently significant, the single ratios have but little value."

To the present writer there would seem to be no valid reason for restricting the comparison to those igneous rocks which show more than 70 per cent of silica, especially as these include nearly all of the greatest group of potash-rich rocks, the granites and rhyolites, and also as the average percentage of silica in the meta-sedimentary rocks with which they are compared is only 60 to

65 per cent. While the double relationship  $\left\{ \begin{array}{c} K_2O > Na_2O \\ \text{and} \\ MgO > CaO \end{array} \right\}$  is

the most significant and the single relationship of K<sub>2</sub>O > Na<sub>2</sub>O or MgO > CaO is of little or no critical importance when standing alone, the writer believes that either of these relations, if supported by notable excess of alumina, has very considerable critical value.

Each of the criteria suggested has its "limit of error" which

<sup>1</sup> *Op. cit.*, p. 301.

with the data at present available cannot be determined. For this reason the criteria cannot be applied automatically without the exercise of judgment and discretion on the part of the investigator. It should be especially remembered that if the rocks under investigation have been subjected, either before or after the development of their foliated structure, to severe igneous or hydrothermal

TABLE II

	I	II	III
SiO <sub>2</sub> .....	57.35	49.59	61.62
Al <sub>2</sub> O <sub>3</sub> .....	16.29	14.91	19.98
Fe <sub>2</sub> O <sub>3</sub> .....	3.15	.52	3.46
FeO.....	4.36	10.46	2.57
MgO.....	2.41	2.02	1.24
CaO.....	5.66	1.96	.62
Na <sub>2</sub> O.....	4.50	1.33	1.78
K <sub>2</sub> O.....	3.39	3.51	5.35
H <sub>2</sub> O—.....	.15	.16	.21
H <sub>2</sub> O+.....	.70	3.17	2.23
TiO <sub>2</sub> .....	1.07	1.03	.56
ZrO <sub>2</sub> .....	tr.	none	
CO <sub>2</sub> .....	.46	9.40	
P <sub>2</sub> O <sub>5</sub> .....	.70	.47	
MnO.....	.12	1.10	
Others.....	.24	.43	
Total.....	100.55	100.06	99.62

I. Fresh diorite porphyry 25 feet from vein, Wellington mine, Breckenridge, Colo. W. T. Schaller, analyst.

II. Altered diorite porphyry 10 feet from vein, Wellington mine, Breckenridge, Colo. W. T. Schaller, analyst.

III. Pinal schist, Ray district, Arizona. Analysis made for Dr. F. L. Ransome by R. C. Wells.

metamorphism, the criteria are not applicable, for such metamorphism involves important additions and losses of material. For example, analyses I and II of Table II taken from Dr. Ransome's report on the Breckenridge district, Colorado,<sup>1</sup> show that in the hydrothermal metamorphism of a diorite porphyry there has been a much greater depletion in lime than in magnesia and that there has been an accession of potash and loss of soda, yielding a

rock in which the double relationship  $\left\{ \begin{array}{l} K_2O > Na_2O \\ \text{and} \\ MgO > CaO \end{array} \right\}$  is present.

<sup>1</sup> F. L. Ransome, "Geology and Ore Deposits of the Breckenridge District, Colorado," *Prof. Paper U.S. Geol. Surv. No. 75* (1911), p. 96.

The same result is brought about by the hydrothermal alteration of monzonite porphyry in the Clifton-Morenci district as described by Lindgren,<sup>1</sup> and Dr. A. C. Spencer has shown the writer unpublished analyses exhibiting similar changes as a result of hydrothermal metamorphism of porphyry in the Ely district, Nevada. It is evident therefore that the chemical criteria must be applied only to those foliated rocks which the microscope shows have *not* been subsequently subjected to weathering or to igneous or hydrothermal metamorphism, in other words, to *fresh* foliated rocks. In those rare instances where igneous or hydrothermal metamorphism has affected the rocks previous to the development of foliation there should usually be some evidence of it in the presence of mineralization in associated schists.

An instance of the successful application of chemical criteria as an aid to determining the origin of a schist in a mining district is afforded by analysis III of Table II, hitherto unpublished, which I have been permitted to use through the courtesy of Dr. F. L. Ransome. This schist consists predominantly of quartz and sericite with subordinate chlorite, biotite, andalusite, magnetite, and zircon. It forms part of the Pinal schist of the Ray district, Arizona, which is shown by bands of pebbles, arkosic and quartzitic phases to be for the most part of sedimentary origin. This schist is older than the mineralization, and microscopic study indicates that the specimen analyzed has suffered no important mineral changes since the development of the foliation. It will be noted that there is about twice as much magnesia as lime in this rock and about three times as much potash as soda. Alumina is present to the extent of 10.30 per cent above that necessary to satisfy the lime and alkalis present. The strong development in this rock of these three chemical characteristics points to its having been subjected to the processes of weathering and assortment previous to metamorphism, in other words, indicates a sedimentary origin, and affords, the writer believes, a valuable *adjunct* to textural and structural evidences in interpreting the origin of the rock.

<sup>1</sup> W. Lindgren, "The Copper Deposits of the Clifton-Morenci District, Arizona," *Prof. Paper U.S. Geol. Surv., No. 43* (1905), p. 168.

## II

The question of the value of chemical criteria is part of the much broader question of the extent to which transfer of material goes on in rocks during purely dynamic metamorphism. This is a problem of importance to geologists and one which has received little attention. The data at present available are of somewhat conflicting character. Certainly many who have worked in regions of metamorphic schists must have been impressed by the extent to which portions of the metamorphic series, originally different, have preserved their individuality. Dikes, though rendered schistose and perhaps pinched out in places, still show sharp borders giving no evidence of extensive interchange of material with the bordering rock; limestone beds in the series still show sharp borders after metamorphism, and original sedimentary beds may still be recognized as such by the development of *knoten* or of particular minerals in some of them and not in others. In rarer cases ore deposits have been deformed in dynamic metamorphism without destroying the integrity of the ore bodies or causing any migration of the ores into the wall rocks as in the case of the Milan, N.H., deposit described by Emmons.<sup>1</sup>

As the writer pointed out in his earlier paper,<sup>2</sup> many of the granite-gneisses of Georgia described by Dr. Watson are still normal granites in composition although showing marked evidence of dynamo-metamorphism. To quote Dr. Watson:<sup>3</sup> “. . . the granite-gneisses differ from the more massive rock phases [granite] simply in the marked banded or foliated structure. These are secondary structures induced by profound and long-continued dynamo-metamorphism, acting on an originally massive rock, similar, in mineralogical and chemical compositions, to the existing massive granite areas studied.”

If it can be shown that important transfers of material may take place during dynamo-metamorphism, it still remains to be determined whether such processes are common or exceptional in the

<sup>1</sup> W. H. Emmons, “Some Ore Deposits in Maine and New Hampshire,” *Bull. U.S. Geol. Surv.*, No. 432 (1910), pp. 50-60.

<sup>2</sup> *Jour. Geol.*, XVII (1909), 450-51.

<sup>3</sup> *Bull. 9-a, Geol. Surv. of Georgia*, p. 263.



metamorphic rocks now exposed at the earth's surface. It is commonly supposed that under conditions of dynamo-metamorphism rocks are relatively dry and pore-space is reduced to a minimum and such conditions would appear to be particularly unfavorable for the transportation of material through long distances in solution. Certainly the writer has seen little in his personal experience with the crystalline schists of New England and the Rocky Mountains to suggest migration of material under such conditions through more than very small distances. A number of years ago the writer, by averaging a very large number of analyses of clays, shales, slates, and pelite schists, attempted to prepare a series of curves to illustrate the chemical changes during the metamorphism of a clay into a pelite schist. The data used were not regarded as sufficiently complete in all particulars to justify publishing the curves. They showed marked loss of water and carbon dioxide but were suggestive of considerable stability in most of the other constituents, with the possible exception of silica.

It is well known that the development of platy minerals is a characteristic feature in dynamo-metamorphism. From the department of geology of the University of Wisconsin has come the suggestion that this process may exert a controlling influence upon the composition of the rock, constituents unnecessary for the formation of the platy minerals being removed during the progress of the dynamo-metamorphism. While suggested as a general law, the actual evidence thus far offered in support of this hypothesis has involved only the expulsion of silica from highly siliceous rocks. The data offered by Mr. Trueman<sup>1</sup> in evidence of such transportation of silica in the Waterloo quartzite of Wisconsin are suggestive and all similar data should become a matter of record. It is shown that while some bands of sericite schist parallel the bedding planes of the quartzite, others transgress them, and it is argued that the sericite schist of these transgressing shear zones has been produced directly from the impure quartzite by the expulsion of silica during the shearing process. Other hypotheses are, however, worthy of consideration. The zones of sericite schist which transgress the bedding planes may represent

<sup>1</sup> *Op. cit.*, pp. 302-6.

fracture zones which later became the locus of shearing movements. All that is required to produce the chemical changes observed is the removal of silica by waters circulating along such fractures. It is also impossible in this region to eliminate the possible effect of igneous rocks as a source of energy which might result in such changes. The Waterloo quartzite outcrops only in small ledges separated by large areas covered by glacial drift. Pegmatites which appear to be earlier than the shearing of the quartzite cut this rock in certain of the ledges. Although no pegmatite outcrops at the locality where the samples analyzed were taken, it is impossible to say that it does not occur close by beneath the drift cover.

Whatever may be the facts in regard to the mobility of silica under certain conditions, it is beyond question that in the metamorphism of many sedimentary series the quartzite members preserve their integrity even when the associated argillaceous beds are rendered highly schistose, nor do the latter show any marked accession of silica. It has been suggested that a talc schist is the characteristic metamorphic equivalent of limestone as a sericite schist is of quartzite, but here again we are confronted with numerous field observations showing abrupt passages from crystalline limestones to argillaceous schists and to quartzites, even in severely metamorphosed series. Furthermore, with the possible exception of the expulsion of silica, the development of platy minerals during dynamo-metamorphism would seem to be a process ill suited to the accomplishment of any considerable changes in chemical composition, for the platy minerals that are characteristically developed in schists during dynamo-metamorphism are minerals of extremely variable composition, and the same elements enter into the makeup of a number of them. For this reason they are especially adapted to *accommodate* original differences in composition both through variation in the relative proportions of the different platy minerals developed and through variations in composition of each of these minerals.